Polarization Insensitive Antenna Remoting Link with Frequency Conversion Gain

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***Abstract*—We demonstrate a novel photonic link that simultaneously achieves frequency conversion, optical amplification, polarization sensitivity elimination, and fiber dispersion effect minimization. The link also uses low loss and less expensive phase modulators to replace intensity modulators and thus eliminates modulator bias problems.**

PRESENTLY, most RF photonic links simply use optical waves as carriers to transport RF signals through optical fibers. Other RF communication functions, such as signal generation, signal up–down conversion, amplification, and filtering, are still done in the electrical domain, although it has been shown that these RF functions can also be accomplished optically [1]–[5]. These simple photonic links, although necessary for introducing and fitting photonic technology into the existing RF infrastructure, do not utilize the full potential offered by photonics. As photonic technology is more accepted in the RF world, sophisticated photonic links that are able to perform multiple signal processing functions become increasingly desirable.

We have demonstrated previously a technique called Brillouin selective sideband amplification (BSSA) [6], [7] for photonic RF signal amplification and signal processing. In this paper, we describe a simple and elegant scheme that utilizes the BSSA to eliminate many practical problems and make multifunctional photonic links feasible. In particular, we demonstrate a frequency down–up conversion photonic link that has no polarization sensitivity, no need for biasing the modulators, no fiber dispersion induced signal fading, increased optical power handling capability, built-in optical amplification, and increased signal conversion efficiency.

As illustrated in Fig. 1, light from the signal laser first passes through a modulator and is modulated by a local oscillator (LO) signal. The modulator can either be an intensity modulator or a phase modulator. The phase modulator is preferred because it is easier to make, has lower loss, and needs no bias. The LO-modulated signal light is then coupled into a standard single-mode fiber through a polarization beamsplitter (PBS1) whose passing axis is aligned with the polarization state of the signal light.

After transmitting to the remote site through the single-mode fiber, the polarization state of the signal light is no longer linear and varies when the fiber is disturbed. A second polarization beamsplitter (PBS2) is then used to separate the two polarization components of the signal light into two paths. A 90° Faraday rotator is placed in one of the paths to rotate the polarization state of light in the path. The two output ports of PBS2 are pigtailed with polarization-maintaining (PM) fibers and the polarization component in each port is aligned with the slow axis of the corresponding PM fiber. The two PM fiber outputs are then connected with the two PM fiber pigtails (the slow axes of each pair of connecting fibers are aligned) of the phase modulator from opposite ends. The light beams passing through the phase modulator are automatically recombined by PBS2 and coupled back into the single mode fiber. Because the oppositely travelling light beams have the same polarization direction in the modulator at all times (independent of the polarization perturbation in the long fiber), they are equally modulated by the RF signal. Consequently, this PBS/modulator ring arrangement eliminates the polarization sensitivity of the modulator [8].

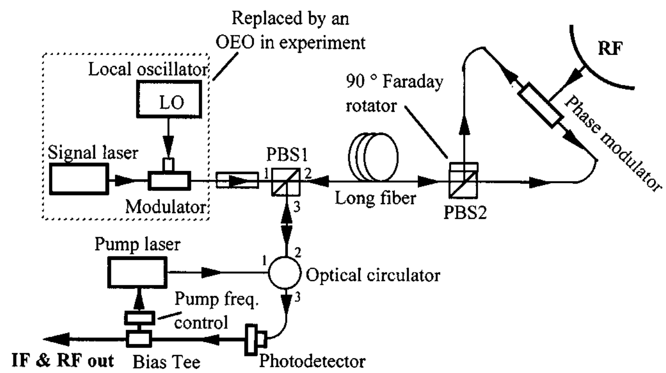

Fig. 1. The schematic of the link. The ring arrangement of PBS2, the Faraday rotator, and the modulator effectively eliminates the polarization sensitivities of the modulator and the Brillouin amplification. The pump laser is responsible for the amplified frequency conversion and phase-to-intensity modulation conversion. The bias-Tee after the photodetector is used to separate the dc component from the high-frequency components (IF, RF, and LO) in the photocurrent. This dc component is then used to stabilize the relative frequencies of the pump and the signal lasers.

Because of the 90° Faraday rotator in the modulator ring, the polarization state of the backward-going light beam in the fiber is orthogonal to the polarization state of the forward-going light beam at every point in the fiber. Finally, the backward-going beam is separated into port 3 of PBS1 and is directed to the photodetector via an optical circulator. The photodetector is directly connected to a bias tee which separates the dc (or low-frequency) and high-frequency (IF, RF, and LO) components of the received photocurrent. As will be discussed later, the dc component is used for relative frequency locking of the lasers.

On the other hand, the pump beam is directed to enter port 3 of PBS via the circulator. The polarization of the pump is so

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adjusted that the pump beam exits port 2 of PBS1 and enters the single mode fiber. After passing through the PBS2/modulator ring, the pump beam is fed back into the single mode fiber and enters port 2 of PBS1. Because of the action of the ortho-conjugator ring, the polarization state of the backward-going pump beam is orthogonal to the forward-going pump beam everywhere along the fiber. Finally, the pump beam exits port 1 of PBS1 and is attenuated by the isolator.

To prevent the relative frequency drift between the signal and the pump lasers, a novel and simple circuit was also implemented. The circuit is based on the fact that when a signal sideband is optimally amplified, the received dc signal in the photodetector is also maximized, as shown in Fig. 2. It is evident that when the pump power is below the SBS threshold of 15 mW and the lower LO sideband is not amplified (the Stokes of the pump is tuned away from the LO sideband), the received dc voltage is small ($\sim$0.15 volts), mostly contributed by the signal carrier. However, when the LO sideband is selectively amplified (when the Stokes is aligned with LO sideband), the received dc voltage is significantly increased, largely resulting from the amplified LO sideband. Even for the case that the pump power is above the SBS threshold, the photovoltage generated by the amplified LO sideband (when LO sideband is aligned with the Stokes) is still significantly larger than that generated by the SBS power (when LO sideband is not aligned with the Stokes). Using a bias tee to monitor the dc component from the photodetector, the frequency of the pump laser can be easily controlled by maximizing the dc signal.

It is important to note that the forward-going pump beam always has the same polarization state as the backward-going signal beam, which allows optimized Brillouin amplification everywhere along the fiber and eliminates polarization sensitivity of the Brillouin amplification process [9].

It is also important to note that almost all devices in the setup have multiple functions. The pump laser is used both for Brillouin signal amplification [6] and for phase to amplitude modulation conversion [7]. The two functions of the first modulator are to generate LO subcarrier and to reduce the unwanted Brillouin scattering of the signal light. PBS1 is used first to combine the signal and pump beams into the single mode fiber, and second to direct them into different paths after they return from the remote site. Even the single-mode fiber is used both as a signal transmission medium and as a gain medium for Brillouin amplification. Finally, the ring arrangement at the remote site, including PBS2, the Faraday rotator, and the phase modulator, has three functions: 1) returning the modulated RF signal; 2) making the modulator polarization-insensitive; and 3) making the Brillouin amplification polarization-insensitive.

To further simplify the link, we use an optoelectronic oscillator (OEO) [5] in the experiment to replace the local oscillator, the modulator, and the signal laser, as shown in Fig. 1. The OEO directly generates a stable and spectrally pure 10-GHz subcarrier that can be used for frequency down–up conversion. The phase noise of the OEO output was measured to be -140 dBc/Hz at 10 kHz away from the carrier [10]. Fig. 3(a) and (b) illustrate the optical frequency spectra of the OEO, the pump laser, and the Stokes frequency of the pump laser's Brillouin scattering. By tuning the frequency of the pump laser, the frequency of the backscattered light (called the Stokes frequency)

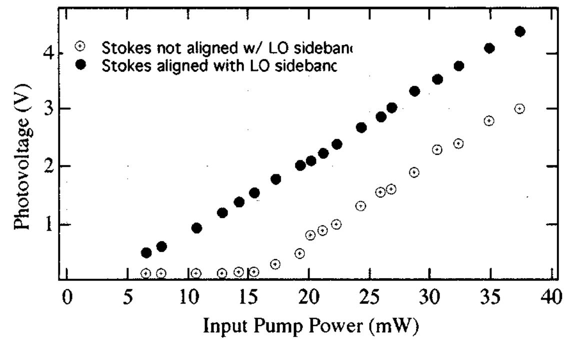

Fig. 2. Experimental results illustrating the fact that the generated DC photocurrent or voltage in a photodetector strongly depends on whether the sideband is optimally amplified. This fact is used to lock the relative frequency of the pump and the signal lasers.

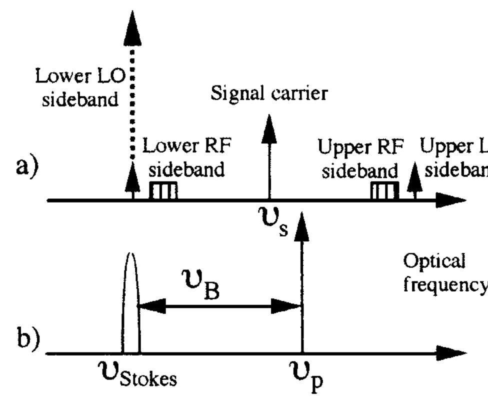

Fig. 3. Spectrum diagram illustrating BSSA-assisted signal up–down conversion. (a) The spectrum of the signal beam with modulation sidebands, where ν_S is the carrier frequency of the signal beam. (b) The frequencies of the pump beam (ν_P) and its Stokes wave (ν_{Stokes}). When the Stokes is aligned in frequency with the lower LO sideband, the sideband is significantly amplified. The beat between the amplified LO sideband and the lower RF sideband in photodetector generates amplified down-converted signal, while the beat between the amplified LO sideband and the upper RF sideband generates amplified up-converted signal.

can be made to overlap with one of the phase modulation sidebands of the signal beam to amplify the sideband. The amplification of this modulation sideband will break the perfect amplitude balance of sidebands of a phase modulation and cause the phase modulation to convert to an amplitude modulation [7].

One may amplify either an LO sideband or an RF sideband to obtain amplified IF and RF signals at the receiver. However, amplifying the LO sideband has the advantage of having wide amplification bandwidth and signal conversion bandwidth [6]. When the lower LO sideband is amplified by BSSA process, the beats of the amplified LO sideband with the lower and upper RF sideband in the photodetector produce down-converted and up-converted IF signals respectively, while the beat between the amplified LO sideband and the signal carrier produces an amplified LO signal.

In the experiment, the RF and LO frequencies were chosen to be 9.9 GHz and 10 GHz, respectively, and the expected down converted signal should be at 100 MHz. Fig. 4(a) illustrates that without BSSA present (i.e, with pump laser turned off), no down-converted signal at 100 MHz was detected. However, when the pump laser was turned on and tuned to amplify the

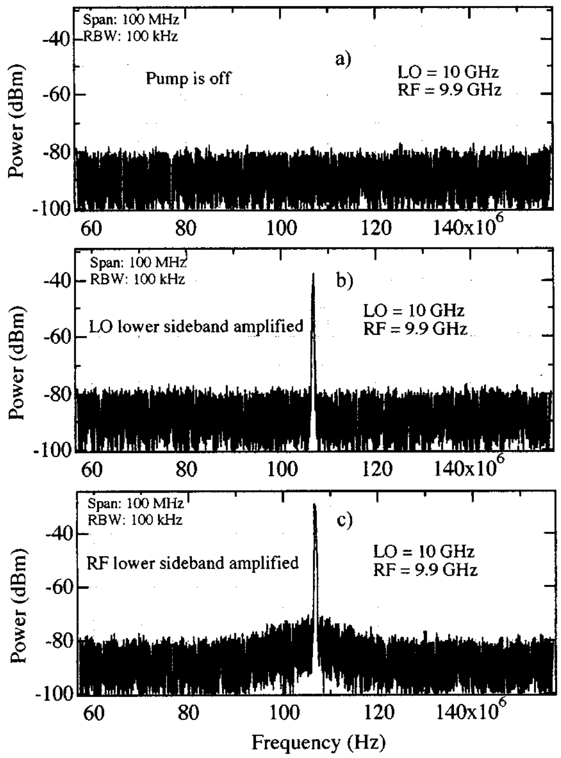

Fig. 4. Experimental results illustrating BSSA assisted frequency down conversion. (a) No Brillouin amplification. (b) LO lower sideband is amplified by aligning with the Stokes frequency of the pump. (c) Lower RF sideband is aligned with the Stokes frequency of the pump.

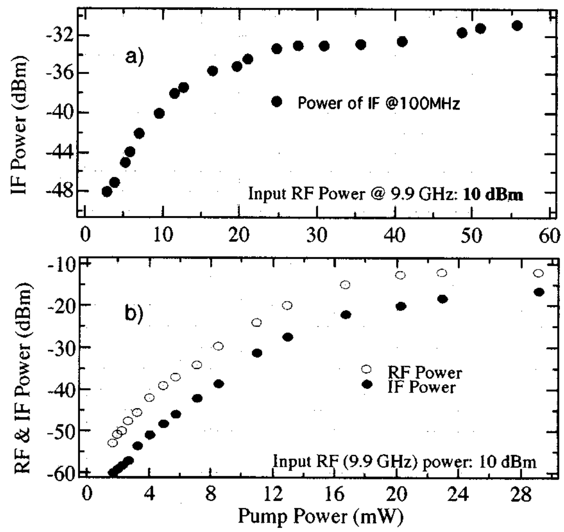

Fig. 5. (a) IF power as a function of pump power when the lower LO sideband is aligned with the pump Stokes frequency and amplified. (b) IF and RF power as function of pump power when the lower RF sideband is amplified. Note that due to the nature of phase modulation there are no received RF and IF powers when BSSA is not present.

lower LO sideband, the down-converted signal at 100 MHz was immediately detected and the result is shown in Fig. 4(b). Similarly, when the pump laser's Stokes frequency was aligned with the lower RF sideband, the 100 MHz down-converted signal was also detected, as shown in Fig. 4(c).

With the experimental setup of Fig. 1, the stimulated Brillouin scattering (SBS) threshold was measured [9] to be 15 mW. However, BSSA has no threshold and significant signal amplification and down-conversion was observed even when the pump power was much lower than the SBS threshold. Fig. 5(a) illustrates the IF power as a function of pump power when the lower LO sideband was amplified by the BSSA process, while Fig. 5(b) shows both the RF and IF power as a function of the pump power when the lower RF sideband was amplified. It is evident that only a few milliwatts of pump power would sufficiently amplify LO or RF sideband and hence convert signals from RF to IF.

It is intriguing to find out that the down- (or up-converted) signal corresponding to Fig. 4(b) and (c) should be nonexistent with a simple theory which considers a phase modulation sideband of either the RF or the LO being selectively amplified. On the other hand, the down- and up-converted signals are nonmistakenly strong in all the confirmation experiments and relate well with the simple picture of Fig. 3. A modified theory needs to be developed to explain the curves in Figs. 4 and 5.

In summary, we demonstrated a simple and elegant multifunctional antenna remoting link that simultaneously accomplishes signal up–down conversion, optical amplification, polarization sensitivity elimination, and minimization of fiber dispersion-induced signal fading. In addition, the link uses phase modulators to replace amplitude modulators and thus eliminates the needs for modulator biasing and bias stabilization. Finally, a low phase noise OEO was used in the link to directly generate a LO subcarrier for frequency conversion.

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